Computer Networking and Information Systems in Radiation Oncology

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I. INTRODUCTION

Quality patient care depends critically on the efficient management and availability of accurate information. There are many challenges involved in organizing and communicating information in radiation oncology (RT). As our planning and delivery systems become more complex and the amount of available data increase, a comprehensive information management scheme becomes a prerequisite to correct treatment delivery.

Medical informatics is the science concerned with the organizational management of information in support of patient care, medical education and medical research. This includes acquisition, storage, retrieval and optimal use of medical information for problem solving and decision making. Medical informatics combines data from and interfaces between a large group of disciplines. It also involves understanding evolving technology and relationships and standards by which this information can be managed. The RT clinic represents a sub-system of the medical informatics world. Radiation therapy treatments embody many facets of modern medical informatics, since medical professionals and staff work closely using computer-controlled equipment and an abundance of patient and machine data for optimization of complex techniques for treatment planning, delivery and verification. The information system (IS) provides the backbone for communication, documentation and quality control and must integrate all necessary data/images in a seamless, reliable, efficient manner. The IS also provides the capability for numerical and statistical analysis of this wealth of data.

As RT technology and technique have advanced, the IS have become electronic. This creates an additional level of complexity revolving around the electronic environment. Specifically, modern electronic IS are built on networks of computers connected in complex arrays, running sophisticated software, to provide transparent and seamless information availability to the users. Computers act as servers, controllers and interfaces.

Investment of human and capital resources in IS and networks is inevitable and ongoing. The quality and availability of information in the clinic directly influences the quality of patient care rendered. This paper describes basic networking configurations and communications, followed by general to specific issues related to the IS that may be used in RT treatments.

II. NETWORKS

The network provides a data communication system between a group of interconnnected computers. The computers on the network share information, application software and peripheral devices such as printers. The network may be a local area network (LAN), limited to a single division or small group in one geographical location. A wide area network (WAN) brings a larger geographical area into a single network. An internet is formed when two or more independent networks are connected to allow access to information and services in a controlled manner. Specific hardware and software for communicating information and data between computers has been developed. This allows the users to harness the power of multiple computers and to access data from an almost infinite array of resources. There is an abundance of information about networks available on “The Internet” as well as in various books (1,2).

A. Hardware

Network hardware components are the engines, wires and switches that allow the network to function. Network hardware can be compared to a railroad track system. The train terminal yard has a concentration of tracks and services much like the computer server on the network. There are many such terminal yards around the country, representing similar or differing services and suppliers. Once a train has been loaded with cargo, which represents the information or data packet on the network, it leaves the terminal yard through switches, which put the train on the correct track. Reaching the final destination may involve multiple switches and travel through other terminals. The railway system is designed to transport as much cargo, in a timely fashion, without train collisions and cargo losses as possible. The computer network is designed in the same way, to communicate data accurately and quickly. The hardware most common to networking systems can be divided into servers, workstations or clients, connectors, which may be topology specific and peripherals.

1. Servers

The server provides a method for many users to share resources such as data (images/files) or peripherals. The server must be designed to manage a large number of files and high data throughput. It must also be designed to operate with maximum time between failures and with redundancy for failure recovery. The server must provide access for all authorized users to any available data as quickly as possible. Server design depends on the scope and size of the data resources the network users expect to service. The specifications would be quite different for a medical imaging picture archival and computer system (PACS) than it would be for a secretarial pool servicing physician notes. Servers are usually power machines with large amounts of memory and disk space. Over the last decade, main frame servers have been replaced with power personal computer (PC) machines, due to the rapid increase in capability of the PC.

2. Workstations

The workstation or client has evolved from the serial terminal connected to a mainframe down the hall to powerful PC workstations. The client machines connect to the server over the network through a topology-specific network interface card (NIC). Access to resources and data is controlled at switches and by the server. As the price has dropped and the power of PCs has increased, more client machines are capable of running power applications locally, instead of over the network. Early network systems with only terminals as clients required that any application was run on the server and data transmitted to the terminal. For applications in common use today, this would not be feasible due to the memory, computation and display requirements. The network can run most efficiently if much of the computing power is derived from the client.

3. Peripherals

Various peripheral devices may also be present on the network. These include additional monitors for viewing data remote to workstations, such as in treatment rooms; printers, text and image quality; bar code readers for patient specific data, digital cameras and scanners. Each of these must be configured to the type of network and operating system that is present.

B. Software

Most networking software supports any of the existing network topologies (**C**.1). There are a number of server software products that can be used to network to clients running various operating systems.

1. Servers

The server software provides an operating system that manages whatever resources are assigned to the server. This may include files and disk storage, printers and peripherals, remote connections, etc. The network operating system on the server must support multi-tasking, provide access to central applications and support a large number of interrupts. The server software manages and maintains client and peripheral addresses and connectivity data. The server software is an administrator for network organization, integrity and authorization for access to the data area it is responsible for. The server software is also responsible for monitoring and recovering from errors/failures. The server software can be run on many different hardware platforms (PC or RISC based) and must integrate with other servers, even if they are not running the same operating system. Common examples of server software include Novell Netware, Microsoft Windows NT Server, IBM OS/2 Warp and Unix. Additional software for redundancy/backup and recovery may also be needed.

2. Clients

The clients or workstations may have almost any configuration, as long as they have a NIC to connect to the network. Most network clients are computer workstations, capable of running applications locally with information that may be located at a server. The client software is composed of an operating system and an array of applications software common to the network. The operating system could be Windows, Unix, OS/2, Mac or other system. Depending on the speed with which the user wants results, most applications are now run on the client, only storing data files and information out on the network. These applications include graphics production, word processing, data analysis, IS, etc. In many cases parts of the application run on the server and parts run on the client in an efficient way.

C. Putting it Together (Connections)

1. Topologies

An important part of network design is to determine the way the computer components are connected(topology) and the network medium for communication. The choice is effected by the number of connections, the distance between connections, required data transmission rates, response times and cost.

Bus topology - All workstations connect to the same cable segment (Fig 1). This is a common solution in early and small networks. Any message is transmitted along the cable and is visible to any workstation on the network. In addition, the daisy chain method of connecting the workstations means that if any segment fails, the entire network is down. The Institute for Electrical and Electronics Engineers (IEEE) has developed specifications for configuring LANs. Specifically, to control network traffic, a protocol called carrier sense multiple access with collision detection (CSMA/CD)was defined (3). In a bus topology, each station listens to see if another station is sending a message before or while that station sends a message. Cabling for the bus topology is usually thin wire coaxial cable.

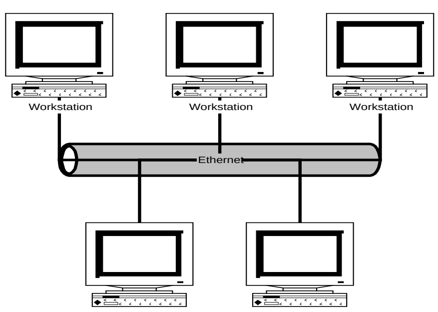


Figure 1. Single cable bus topology

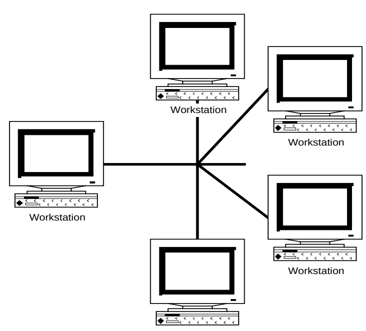


Figure 2. Star topology

Star topology - The star topology is similar to the bus, except that all of the workstations are connected to a central point, either the server directly, or a hub. The configuration resembles a star or wagon wheel (Fig.2), has the capability of running long distances on each spoke and is typically run with twisted pair (4 wire) at 10Mbits per second (10 base-T) or 100 base-T. Again, all clients can see any message on the star, but if one segment fails, no other segment is affected.

Ring topology - The token ring topology connects all workstations to a common ring. These are usually cabled with twisted pair and can operate above 10Mb per second. The token ring communication works by passing a token around the ring (Fig 3). Each workstation only acts when it receives the token. If the token is empty, a workstation may append a message to the token. If the token caries a message, each workstation checks to see if the message is addressed to it. After the message is received, the token is updated so that the sender can be told the message is received. Then the process begins again.
Disabled workstations can be dropped from the ring, not effecting other stations. The details of this specification are described in the IEEE standard 802.5 (4).

FDDI topology - Fiber distributed data interface (FDDI) is based on dual 100Mbit/sec fiber-optic rings (Figure 4). This can support a large number of workstations and has the largest bandwidth available in common network connections. The fiber can also extend up to 2 kilometers.

In many cases, some combination of topologies may be used. FDDI backbones are becoming common, with 10 base-T or 100 base-T star networks connected to the backbone.

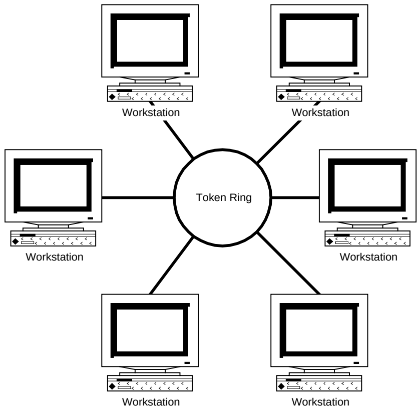


Figure 3. Token Ring topology

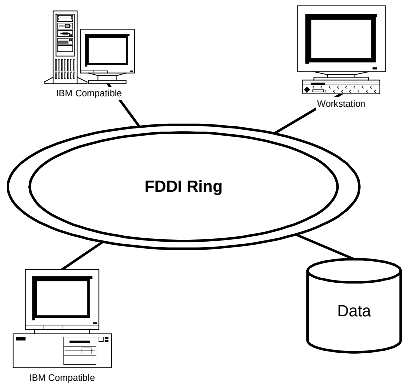


Figure 4. FDDI Ring topology

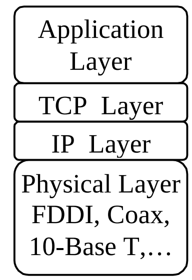


Figure 4a. TCP/IP

2. Communication Protocols

Communication protocols are the heart of reliable, high-speed data transfer. A standard protocol for network communication is transmission control protocol and internet protocol TCP/IP. Other protocols such as internet packet exchange IPX and open systems interconnect (OSI) operate in a similar fashion.

TCP/IP is a standard set (suite) of protocols stacked together to allow communication between any two systems which may be on different LANs. This TCP/IP stack is four layers (Fig.4a), each carrying specific information that other systems understand for that layer. The lowest (physical) layer carries network access information, with specific information following IEEE 802 guidelines. This allows the information to be put onto the LAN. The second layer is the IP address information for conveying the information to a second LAN or network. An IP address consists of a four-byte word, which is unique to a given piece of hardware. Both transmitting and destination IP addresses are known in the IP layer. The third layer is the TCP or transport layer which segments the information for the transmitting location. The destination TCP layer verifies and acknowledges good/complete data receipt. The TCP/IP software resides in routers or network gateways. The fourth (top) layer contains the data to be transferred. This is usually application specific information such as file transfer protocol (FTP) to transfer files between systems; network file system (NFS) to extend a file system to another network or computer; X-windows for remote sessions, simple message transfer protocol (SMTP) for mail or DICOM SOPs (**IV.A.**1). Details on TCP/IP are available (5,6).

3. Connectors

The method by which the data is directed to the correct location is important. Within a LAN, all workstations have access to every message, and therefore traffic and time can be a problem.

Hub - The hub is a signal concentrator, which allows the signal information to be shared among all stations in a LAN. The hub is essentially a signal repeater, receiving a data packet and then sending the same data packet out to all of its ports. The hub serves to speed up data availability and increase the number of connected workstations. It does not reduce, switch or otherwise control traffic. In order to increase geographic coverage and manage traffic volume, network design usually calls for several smaller LANs separated by smart connections. LANs can be connected to allow each LAN access to shared resources and data, forming intranets and internets. There are three major types of devices used for connecting LANs; bridges, routers, and switches. Bridges and routers are the most common devices used for connecting LANs. These devices link adjacent LANs and allow users on one LAN to be able to reach resources on other LANs within an organization, with data filtering, so that only those data that need to pass from one LAN to another are forwarded across the link.

Bridge-Bridges filter data between any two LANs by making a simple forward/don't forward decision based on the destination address on each packet they receive from either of the networks they are connected to.

Router-Routers are more complex devices that use network layer protocol information (TCP/IP) within the data to route it from one LAN to another. This means that a router must be able to recognize all of the different Network Layer Protocols that may be used. Routers communicate with each other to allows them to determine the best data route through a complex links of many LANs and avoid putting data on LANs where it is not needed.

Switches -Switches also link several separate LANs and provide filtering between them. A LAN switch has multiple ports, which acts like a fast multi-port bridge since it can support numerous transmissions simultaneously. A switch can increase performance on an organization's network by segmenting large networks into many smaller, less congested LANs, while still providing necessary interconnectivity between them. Each port has dedicated bandwidth, without requiring users to change any existing equipment, such as NICs, hubs, wiring, routers or bridges that are currently in place.

4. The network infrastructure

The network connections and cable must also be specified to support the traffic and number of workstations, servers and peripherals, and to handle expected and future traffic. Specifications for 10Mbit or 100Mbit, twisted pair or thin wire, in a star topology or connected to an FDDI ring must be made. Switches, routers and hubs should be placed to separate logical areas of the network into subnets to minimize traffic and maximize efficiency. Security levels and protective configurations should also be determined in the design.

D. Sample Specifications

This section demonstrates sample specifications that apply typically to RT. It is expected that the server system can support storage of necessary data for a RT IS, but not necessarily all data (including radiology data) that may be required. There may be a need for multiple servers for each major application such at treatment planning, record and verify, etc. Data that is available over the internetwork is not needed on the RT network.

1. Server

The server must be able to run large programs and manage a large amount of information, in a failsafe manner. An example server configuration includes power and redundancy, shown in table 1. The server may cost $20,000 to $30,000. A significant portion (20%) of this cost is the server software license for a large number of connections. Each of the major PC and Unix manufacturers markets machines specifically designed to be network servers.

Processor	Dual 400MHz or greater
Bus type/speed	PCI/ 100MHz
Cache	512Mbyte or greater
Memory	384Mbyte DRAM @100MHz (8ns) or greater
Hard Disks	4x6Gbyte or greater hot swap (12Gbyte effective), SCSI, 10,000RPM and one spare 6Gbyte
Drive Controller	100MHz SCSI running RAID 5
Backup Tape	20Gbyte or greater streaming tape (DAT) with SCSI control and appropriate backup software.
CD-ROM	SCSI 12x or greater
Floppy Disk	3.5 inch
Network Adapter (NIC)	PCI 100Mbit/sec, compatible with network wiring
Monitor	14 inch color or monochrome
Uninterruptable power supply (UPS)	Server monitored, 10 minutes or greater capacity.
Network Server Operating System	50 + license Windows NT Server 4.0 or Novell Netware 4.x, or other.

Table 1. Sample specification for a network server.

2. Clients

The clients have enough capability to run necessary applications and communicate with the appropriate server (Table 2).

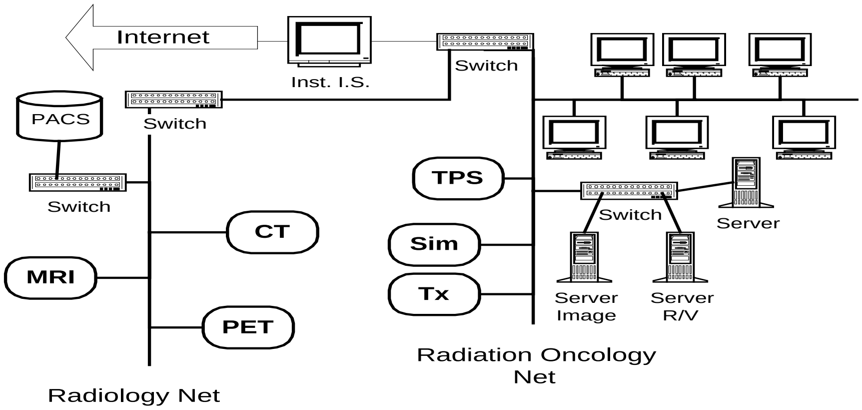
Processor	400MHz or greater
Bus type/speed	PCI/ 66MHz or greater
Cache	256Mbyte or greater
Memory	64 Mbyte DRAM @66MHz or greater
Hard Disk	9Gbyte or greater EIDE 7200 RPM or greater
Drive Controller	Enhanced IDE (EIDE) or SCSI
CD-ROM	SCSI 12x or greater
Floppy Disk	3.5 inch
Network Adapter (NIC)	PCI 10-100Mbit/sec, compatible with network wire
Monitor	19-21 inch color
Video card	4-8Mbyte RAM with 1024x760 and 70Hz refresh
Operating System	Windows 98 or NT workstation, OS2, Mac

Table 2. Sample specification for a power network workstation.

The client pricing can range from near $1000 to over $6000. Word processing clients could have lesser specs than in table 2.

3. Sample Network

A simple possible network configuration is show in Figure 5. This shows the RT network, the institutional network and other departmental networks, and switches in logical and high traffic areas, to maintain bandwidth and redundancy and separate critical systems. Figure 5. Simple network with RT, radiology and the institutional I.S.



III. INFORMATION COMPONENTS

Network hardware and software provide a medium by which systems and individuals can communicate. The IS uses the network to provide critical information to users and devices that need it. A complete IS for RT manages information through data acquisition, presentation, communication, storage and retrieval. Examples include scheduling for patients, staff and equipment, billing and charge capture, picture archival and communication systems (PACS), treatment machine control and treatment verification. The IS must guarantee that the provider or resource will be available to service the patient in the specified manner at the scheduled time and location and that all necessary information is available for the delivery of effective, efficient and compassionate patient care. The components of the IS are information objects.

A. Information Objects

1. General Radiation Therapy Model

There are a large number of information objects involved in medicine and in RT. Objects can be grouped into categories based on the major task or event they are related to. Availability of these information entities may be required at various stages of the radiation therapy process. Each of these objects could be further sub-subdivided into basic information pieces of patient events.

2. Information Objects; Example in 3D Radiation Therapy (3D-RT)

This object model can be completed in the context of 3D-RT. In Figure 6, specific information objects are depicted. Diagnostic data may include MRI, CT volume sets and perhaps other studies, which may include report data in the form of text. Non-imaging laboratory results will also be included in the diagnostic group. This massive amount of information is required to adequately localize target and organs at risk and develop a treatment strategy that will deliver the prescribed therapeutic dose to the target, all in full 3D. Patient data includes demographics, identification information and cumulative data derived from patient visits with the physicians and referring physicians and an assessment of the appropriate patient specific treatment approach. Therefore, the patient data may have many sources, including those outside the department of RT. A qualification test to determine which therapy technique best meets the patient's needs is also part of the record. The conventional and 3D-RT treatment regimen is then defined.

The simulation step may include combining diagnostic and patient data with specific geometry goals and constraints of the therapy delivery system. Adequate information is gathered to supply the treatment planning system with ICRU50 volumes (7) and a reference frame consistent with the planning system and the treatment machine for 3D-RT. Treatment planning brings the simulation and imaging information objects together with treatment machine/device characteristics. This allows the therapy team to develop computer-based, optimized target dose and minimized dose to organs at risk. Whether it involves forward or inverse planning and fixed hand-built or dynamic compensation, the planning system must bring the physicians treatment goal into reality and specify all treatment and reference information related to the accurate and safe delivery of the RT dose.

Whether the treatment delivery method is traditional physical compensation, custom micro-collimation, tomotherapy, dynamic collimator or dynamic multi-leaf collimation, detailed information must be delivered accurately and efficiently to the treatment machine/device. More recent computer-controlled IMRT requires computer optimized, computer-generated and computer controlled treatment delivery. However, even "simple" conventional RT, based on wedges or tissue compensators still requires detailed information for compensator design and orientation. In any case, plan verification for accuracy and safety must be carried out. It may include verification of the treatment devices (record and verify) and the radiation field placement (portal imaging). The computer controlled treatment delivery must be failsafe. Finally, dose record, details of treatment and billing information must be captured in an organized manner.

All personnel related to the treatment delivery are components of the information needed to complete a successful treatment. In 3D-RT, in some cases, intense involvement of staff other than treatment therapists is required and must be incorporated in the IS. Quality control and quality assurance (QA) remains a critical component of each step of the process. As the therapy becomes more complex and intensive, data integrity, clear communication and accurate devices become more important. Although QA is a normal part of any treatment process, in 3D-RT the QA program must ensure against a prolific number of potential errors due to the large amounts of data, complex beam orientations and computer controlled devices.

The scheduling component must be able to reconcile complex schedule data, potentially from multiple sources, so that all information and personnel are available when needed to best deliver patient care. Coordinating staff availability, treatment machine and all patient specific data required can be a difficult task.

IV. INFORMATION INTEGRATION

The information objects defined in the examples described above can be considered pieces of the medical informatics puzzle. In many clinics all of these pieces of information exist, but they are not integrated. The goal of the IS is to integrate all of these entities in a seamless, effective manner as indicated in Figure 7. This encompasses the process by which all components function. A single missing puzzle piece or bad fit can jeopardize the entire system. The relationship between different puzzle pieces may be unidirectional or bi-directional and may complex and sophisticated. The organization of these information objects, their definitions and the communication format and pathway that connects them is the IS.

The simplest version of the IS is the paper patient chart. This IS contains each of the information objects mentioned above, usually separated into sections. Pen, paper and sneakers represent the communication web and all data relevant to this patient treatment is available in the patient chart. Electronic IS have been developed to reduce error, increase efficiency, automate recording and organize large amounts of data (8). The availability of reasonable cost technology has helped. Computer controlled radiation therapy systems have been described (9,10), but these systems only encompass a portion of the informatics problem. The IS must integrate and communicate all data/information necessary for the RT patient to receive a complete treatment. Many of the issues related to IS in RT have been discussed in part, PACS (11, 12), electronic medical record (13), IS (14, 15), information communication (16,17,18). The complete integrated IS links all the puzzle pieces together in an organized fashion.

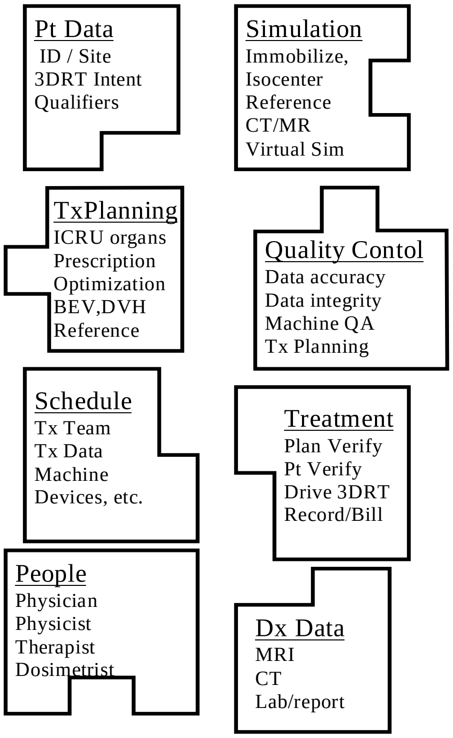


Figure 6. Specific example of key information objects

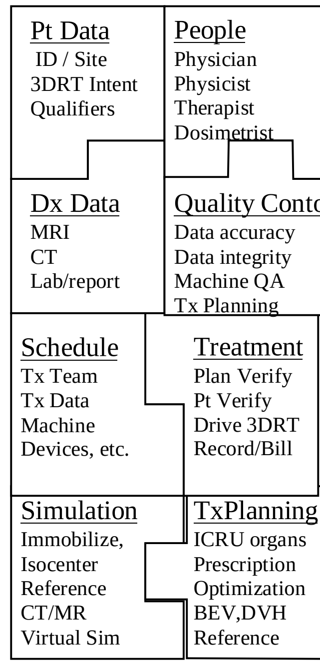


Figure 7. Integration of key 3D-RT 3D-RT information objects.

A. Integrated Information System: Objects and Actions

The information objects in Figure 7 may be large in size and the relationships with other entities within a module or in another module may be complex. Analysis of the entities within one module allows us to understand the relationships that information objects must have with each other and with the end user. The method by which the information model is built, determines its ultimate success or failure and its longevity. An object oriented approach is described (16) and is intended to make the IS open and modular. Only with a standard model can an IS be built that can integrate all the necessary components. The standards allow both interconnectivity ("I got the message") and interconnectivity (" I understand the message") in complex environments. Proprietary tools and secret database formats make universal information integration impossible.

1. DICOM

Digital Image Communication in Medicine (DICOM) is a basis of standards, designed for image communication. The DICOM standard is broadly separated into information objects (e.g. CT study) and service classes, which define the action or service to be performed on an information object. Service examples include storage, query/retrieve and print. In DICOM (19), the information objects are linked by actions. The basic unit of communication is the service object pair (SOP), shown in Figure 8a. Each service acts on an object or in some cases a composite object, containing a number of objects usually found together. A simple DICOM example is shown in Figure 8b.

The information objects (boxes) are connected by actions (arrows). The patient arrives for a visit to see the physician (e.g. RT consult). At this visit, the physician will reference other available data contained in study 1. Study 1 contains information about the study, its components and the modality and procedure used to acquire the series, and the series data for the study. The image series is created by the scanning or other equipment and includes the image data set(s), which are spatially defined in a frame of reference. The findings (report) are included in the series. Note that the images in the series also document the findings. Additional standardized information objects (labeled standard objects) that may include conversion tables, overlays, annotations, etc. are included. The visit may create a second study for additional use in diagnosis or treatment decisions, which will contain the same information objects as study 1. The visit also creates a report of findings (clinician’s note) following consultation. The information objects related to this visit (findings, study 1 data, study 2 data), in addition to detailed information about the department capabilities (Tx options) related to therapy are used as reference objects to develop a treatment strategy for the patient. In some cases, related objects are combined into composite objects, that are treated as single information objects (inclusive dashed line in Fig. 8b).

Other patient visits can be treated exactly the same way. In this manner, the visits and related information objects are organized and related in the same language. This allows many different types of information objects at different stages of a patient’s treatment to be related and communicated. The DICOM standard defines communication protocols that conform to the same IEEE 802 standard as general network protocols to ensure that devices can communicate in a reliable fashion. Transfer of DICOM formatted information fits neatly into the upper (application) layer of TCP/IP or OSI.

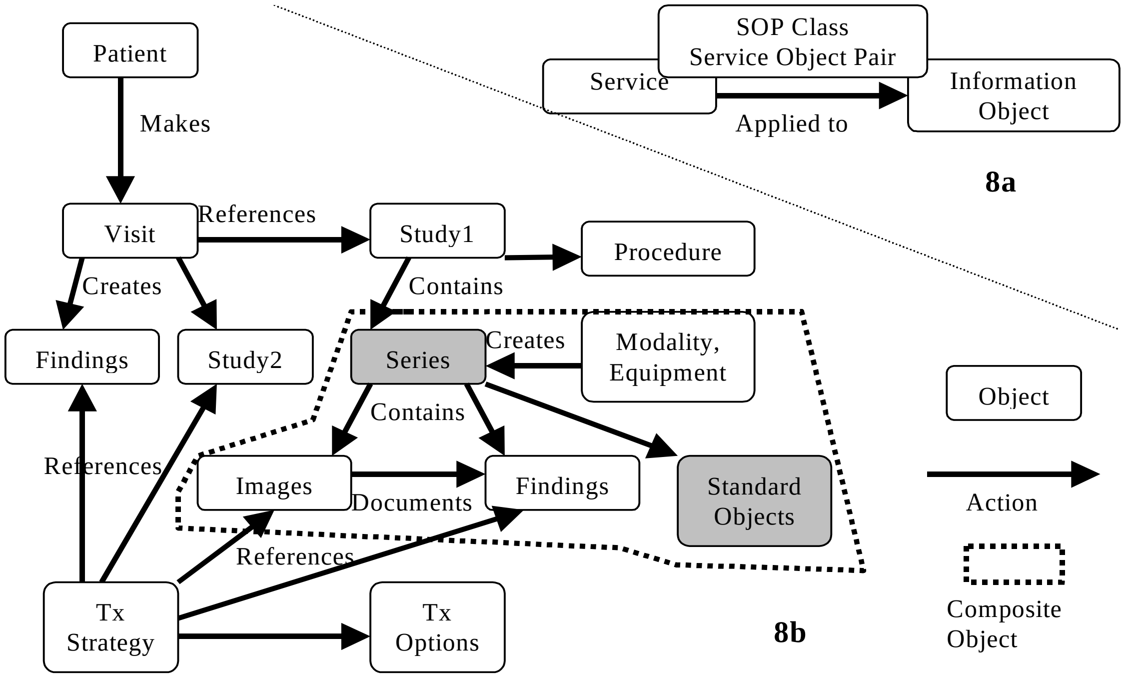


Figure 8. a) DICOM SOP Model; b) Information Objects and relationships for simple patient visit.

2. DICOM-RT

The DICOM standard has been extended to include a number of radiation therapy (RT) objects. DICOM-RT (20) specifies information objects essential to communicating patient specific simulation, treatment planning and treatment delivery information in the DICOM standard. The DICOM-RT (Table 3) objects are treated as a modality in a series in Figure 8 (shaded boxes), and therefore plug easily into the standard.

Table 3. DICOM-RT information objects and definitions (* are in final draft 5/99)

DICOM RT modality (Information Object)	Object Definition
RT Image	RT specific images, such as DRR, EPID digital simulation capture, digitized film.
RT Structure Set	Curves or points representing patient contours and structures.
RT Dose	2 and 3D isodose curves or surfaces, point doses, dose volume histograms
RT Plan	detailed planned data, beams, applicators, fractionation scheme
*RT Beams Tx Record	Record/Verify data, as treated for external beam
*RT Brachy Record	Record/Verify data, as treated for brachytherapy
*RT Summary Record	Summary, cumulative data for entire course/patient

Within each series, each modality is composed of modules, containing specific attributes associated with an object. The attributes are given a unique identifier and coded as to whether they are mandatory or optional. There are 22 RT modules and each modality references multiple modules. The following example shows briefly how RT fits into the DICOM formalism and how RT-series reference other modules. Additional RT series would be listed similarly in items i),ii) and iv).

1) Patient X
    a) Study 1
        i) Series A (RT-PLAN) (could be any RT modality RT-Image, RT- Dose, etc)
        ii) Equipment – used to acquire/generate the series (e.g. planning system or Information system)
        iii) General information objects, common to DICOM
        iv) Plan (RT specific modules and attributes associated with RT-PLAN, or RT modality in i))
            (1) RT General plan (module describing overall Tx plan/course)
            (2) RT Prescription (module detailing Rx based on ICRU50 guidelines)
                (a) RT Tolerance tables (module specifying treatment tolerance parameters)
                (b) RT Patient setup (module detailing immobilization, patient position/setup data)
                (c) RT Fraction scheme 1 (module defining fractionation scheme)
                    (i) RT beams (module containing all beam and field related data; 117 attributes)
                    (ii) RT brachy (module containing all brachy tx related data)
                (d) RT Fraction scheme 2
                    (i) RT beams
                    (ii) RT brachy
            (3) Approval (module containing approval status, not signature)

All specific details required for treatment, determined by the physician prescription and the treatment plan are included in this group of modules inside the modality RT Plan. The detail and format is critical for the data to be understood by another system or device. The RT Treatment Record and Media Extensions was created to handle record and verify data, treatment summary information generated electronically and manually and to facilitate exchange of the RT objects. The data in 3D-RT is so complex, that this type of object organization is the only way that detailed information about the 3D-RT plan can be reliably passed to a treatment delivery device on a commercial or large scale basis. 3D radiation treatment practitioners are encouraged to follow the DICOM models in data storage and communication.

3. Dicom Conformance

DICOM implementation requires a conformance statement specifying which components of the standard a vendor product supports. The conformance statement is written so that an educated user can determine whether two devices/applications are DICOM compatible before purchase. Specifically, whether an application is a service class user (SCU) or a service class provider (SCP) for the many SOPs, and at what level, must be clearly disclosed. A simple example; if application A is an SCP and an SCU for storage of both RT-Plan and RT-Image; and application B is an SCP for RT-Plan and RT-structures, the following DICOM compatibility will occur:

App 1	SOP	App 2	Compatible?	Comment
A	Store RT-Plan to	B	Yes	A is an SCU and B is an SCP for RT-Plan
A	Store RT-Image to	B	No	A is an SCU, but B does not support RT-Image
B	Store RT-Plan to	A	No	A is an SCP, but B is not an SCU for RT-Plan
B	Store RT-Structure to	A	No	A is not an SCP and B is not an SCU for RT-Structures

The DICOM standard is supported by the 3D quality assurance center for the RTOG. Details and examples of how data must be formatted to communicate with the 3D QA center are spelled out on the web site http://rtog3dqa.wustl.edu. All the details of DICOM and DICOM-RT can be found at the NEMA web site for DICOM - www.nema.org/nema/medical/dicom.

4. PACS

One area of specific interest in IS has been image storage and communication, due to the large size of image data sets and the demand for image data in different areas. As therapy has become more advanced and more diagnostic and treatment planning image data is available (and required), the maintenance and transport of huge data sets has become essential. PACS were designed with the primary goal of image archival, storage and retrieval. PACS are designed to maximize efficiency in storage and retrieval yet minimize cost of the service. Depending on the size and number of data sets, and the frequency at which the data sets must be retrieved, the PACS designer must determine the best technology to meet the needs. Do we need Terabytes or Gigabytes, on-line or near term off-line. Radiation therapy PACS or RTPACS specifically allows the additional information needed in radiation therapy to be included in the hospital or departmental storage and archive (11). The DICOM-RT objects facilitate the inclusion of radiation therapy information objects in the conventional PACS. For 3D-RT, the PACS and RTPACS will be essential, since many image data sets may be required to assess and develop a treatment plan for a patient. Standards are essential for the PACS to service a variety of users.

5. Integrating the Rest

The DICOM model for image and related information communication can be a foundation for an IS. Carrying out the treatment delivery, still requires IS control at the delivery device. This control system is built into most modern treatment machines, but the link between the rest of the IS and this control is incomplete. Critical in 3D-RT is the validation and the verification of complex computer controlled treatments. The IS has to know what is supposed to happen and make certain that it does happen. The communication between the planning system and the treatment machine and control of the treatment machine for treatment has been demonstrated (8,10,21). Computer controlled RT demonstrates reduced error rates and treatment effort, even with increased complexity (22). However, these efforts were deliberate, intense developments by strong academic centers. Yet none of these were completely integrated with all treatment related information sources and devices.

Additional items that are either missing or do not interact with the rest of the IS are scheduling and billing modules. Efficient use of personnel and resources can only be accomplished if the scheduling system, and its information objects, is an integral part of the IS. The scheduler can monitor progress of data and other information and best organize the timing for most efficient and effective use of all resources. This could be especially important in 3D-RT, where multiple, time consuming procedures occur simultaneously in preparation for patient treatment. Conflict resolution in scheduling is only effective if the IS is comprehensive and includes all data related to information objects scheduled in radiation therapy.

Billing is imperative to maintain a treatment operation and should be seamlessly integrated into the IS throughout the process. Some schemes have been developed and are in use clinically (14), but they also are not integrated with the entire IS and sometimes not with the hospital IS. Even with 3D-RT, automated billing for complex combinations of services could improve the quality of the treatment system. There has been work on building HL7-DICOM interfaces, so some of this information can be shared.

Finally, interpersonal or inter object communication must be facilitated by the IS. It is not useful to have all the image or plan data sets, if there is no place to approve or annotate the data sets. A yellow sticky note in an electronic IS is not necessarily trivial. These data must also be integrated into the information object scheme.

Perhaps the present scope of DICOM-RT might include what is needed to complete the integration, or another extension may be required. The IS is an ideal vehicle for monitoring and facilitating all aspects of complex treatment procedures. The IS is a resource for research and statistics as well. The complete integration of IS components, communicating via standard protocols, operating on a reliable high-speed network is necessary to improve the quality of care without large additional costs.

V. NETWORK AND INFORMATION SYSTEMS MANAGEMENT

Quality assurance and quality improvement of the IS and the underlying network help manage and maintain accurate, complete and accessible patient data. Quality control procedures for software and hardware checking and the test frequencies must be developed, implemented and recorded. Reliability, data integrity, backup and failure recovery must be guaranteed if the IS is to be used for human radiation therapy.

There should be an individual or group of individuals who are responsible for the management of the network and IS. At larger institutions, information service groups exist. In smaller groups, a dedicated individual might be necessary. Within the RT department, there should be at least one expert on the network and on the IS operation and management.

A. Updating

As technology changes and needs grow, procedures and personnel change. The IS must be able to keep pace with a rapidly changing environment. In 3D-RT, new methods of simulation, treatment plan optimization and treatment delivery will be developed. The IS must be able to integrate new objects and hardware without disrupting its functionality or becoming obsolete.

B. Standards

One way of increasing the probability of successful updates and long life is to maintain and follow standards in software development and equipment specifications. The system should also be modular in design such that hardware and software components can be updated, added or deleted, without major downtime and cost.

C. Backup

Systematic backup and recovery procedures must be in place for a critical IS. An instant backup must be available for use in the case of component failure during a critical procedure. General backup schemes must be in place to guarantee the integrity and availability of the information in the future. This system may well represent the entire medical record for the patient and all information related to the relationship with the medical environment. An example is an available hardcopy of the electronic treatment chart (including complex machine motions), if the IS goes off-line.

D. Costs

The costs of an integrated IS depend on the scope and scale of the implementation. Hardware costs may be substantial, but computer technology continues to improve in value. Personnel costs may also play a part, but it may be argued that a functional IS saves in efficiency what it might cost in personnel to maintain and develop. If the future capabilities for data review and access are considered, the integrated electronic system will be less costly than a paper system. A fully functional IS will cost in excess of $100k-$200k for hardware and software. Personnel costs are in addition. At least one knowledgeable and accountable person should be considered a minimum.

An important point for 3D-RT and especially IMRT is that without a functional IS, the only IMRT that we can accomplish is with fixed wedges and possibly with manual tissue compensation. 3D-IMRT as it is developing absolutely requires an integrated comprehensive IS.

VI. THE INTEGRATED ELECTRONIC INFORMATION SYSTEM

The complete, comprehensive IS will include most of the items discussed previously, and they will all be accessible anywhere on the system with a fail-safe backup. Some questions when looking at IS:

A. Questions to Ask

1) Can my information system
   a) Control and monitor all simple treatment machine parameters (static), mu, collimator settings, rotations, etc.
   b) Control complex device movements, DMLC, Djaw, Moving Gantry+Collimator
   c) Verify complex device movements, DMLC, Djaw, Moving Gantry+Collimator
   d) Integrate treatment devices, blocks, compensators, EPIDs, dose measurement
   e) Schedule all activities and resources involved in radiation therapy across department and across campuses
   f) Perform automated billing
   g) Facilitate communication between users (through annotation at any object level)
   h) Avoid obsolescence
2) Does my information system understand (sending and receiving)
   a) DICOM
   b) DICOM-RT (<u>all</u> information objects, SOP)
3) Is DICOM and DICOM-RT compliance demosntrated/validated; with any and all systems I expect my system to communicate with
4) Does my underlying network
   a) Support the bandwidth and capacity necessary for my information system to perform
   b) Allow easy upgrades with improved hardware/software
   c) Have reliable backup and failure recovery
5) Will my information system integrate seamlessly with my
   a) planning system
   b) simulators
   c) hospital information system , including billing
   d) other clinical information system
   e) PACS
   f) Treatment machine
   g) Patient disease registry (tumor registry)

h) Computerized block cutter
i) Scanners
j) EPID
k) Digital camera
l) Etc.

Is there any IS that does all this? Academic centers and our commercial colleagues are trying to develop such systems. They need our guidance to direct their efforts. The user is obligated to understand the limitations and expectations of the IS installed or being purchased. Clear specifications by the customer, with clear demonstration of expected capability is difficult to achieve, but critical to getting what you need.

VII. CONCLUSIONS

An integrated IS represents a key component in the overall scheme of radiation therapy treatments. The conventional paper chart and "sneaker-net" can not keep pace with the overwhelming amount of data/information that must be organized and maintained for modern treatments. Computer-based electronic charts and IS are being developed that can meet the needs of the increasingly complex radiation treatments. An efficient and well designed LAN and internetwork are critical prerequisites to a functional electronic IS. Following standard protocols for communication and object definition will allow devices from any supplier to communicate critical treatment information. If RT treatments are to continue to become more complex and be successful, the fully integrated electronic IS will be part of it.

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